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FINAL STRETCH ZONE WIDTH DETERMINATION FOR MP35N MULTIPHASE ALLOY

ODREĐIVANJE ŠIRINE ZONE KONAČNOG RAZVLAČENJA MP35N VIŠEFAZNE LEGURE

Originalni naučni rad / Original scientific paper
UDK /UDC: 669.14:539.42
Rad primljen / Paper received: 05.12.2015

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Keywords
- MP35N multiphase alloy
- final stretch zone width
- elastic-plastic fracture behaviour
- microstructure
- J integral

Abstract

This paper presents an experimental elastic-plastic fracture behaviour analysis in order to evaluate a resistance of the aged and unaged MP35N alloy to stable and unstable crack growth. MP35N fracture behaviour has been investigated under static loading conditions, so J-R curve and J_{IC} testing results are presented. Another important task was to obtain and investigate SEM microphotograph of fracture surface for various specimens and to analyse the microstructure in the stretch zone. The results indicate that around the crack tip at the stage of crack initiation mixed loading conditions are predominant. An attempt has been made to determine the final stretch zone width as a fracture parameter for the MP35N alloy. It is possible to correlate results for average SZW with obtained J_{IC} values, and sufficiently good agreement between them is shown.

Ključne reči
- MP35N višefazna legura
- širina zone konačnog razvlačenja
- elastoplastično ponašanje loma
- mikrostruktura
- J integral

Izvod

U ovom radu je predstavljena eksperimentalna analiza ponašanja tretirane i netretirane legure MP35N pri elastoplastičnom lomu usled stabilnog i nestabilnog rasta prsline. Ispitano je ponašanje loma pri statičkom opterećenju, tako da je dobijena J-R kriva, i predstavljeni su rezultati ispitivanja za J_{IC}. Drugi važan cilj je bio izrada i ispitivanje SEM mikrografa površine loma raznih epruveta i analiza mikrostrukture zone razvlačenja. Rezultati pokazuju da je u stadijumu inicijacije rasta prsline dominantno mešovito opterećenje u okolini vrha prsline. Pokazano je određivanje širine konačne zone razvlačenja kao parametra loma legure MP35N. Pokazano je da je moguće je napraviti korelaciju rezultata za srednju vrednost širine zone razvlačenja i dobijenih vrednosti J_{IC}, i prikazano je njihovo zadovoljavajuće slaganje.

INTRODUCTION

Plane-strain fracture toughness K_{IC} is an important material property in design for fracture prevention. Methodology for K_{IC} determination is defined by ASTM standards, /1, 2/. Different specimen configurations and methods are suggested, providing valid results when linear elastic fracture mechanics conditions prevail.

For components experiencing both plastic and elastic deformation at fracture conditions, another parameter has been developed to define fracture behaviour. The failure (crack initiation) occurs when J integral reaches some critical value, which is different for different materials and is considered to be a material parameter. One can thus define the value J_{IC}, which characterizes the toughness of a material near the onset of crack extension. Several methods based on different specimen configuration and loading conditions are developed for J_{IC} determination. The ASTM Standard defines precisely how to determine J_{IC} for each of these standard test methods. The critical J integral value can be obtained from the J-R curve as a value that corresponds to the average stretch zone size, or average stretch zone width (SZW).

STRETCH ZONE WIDTH DETERMINATION METHOD

Apparent increase in crack length during blunting, Δa_B, is often related with the stretch zone (SZ), Fig. 1.

The width of the final stretch zone is considered a fracture mechanics parameter, corresponding to the initiation of stable crack growth δ_i. This parameter is quite difficult to measure, and so it does not have a widespread use. It is nevertheless standardized, at least at the level of recommendation, /3/. The measuring technique includes scanning electron microscopy (SEM). Figure 1 schematically represents the stretch zone width determination.

On the SEM microphotograph of the fractured surface one can distinguish the following areas (zones):

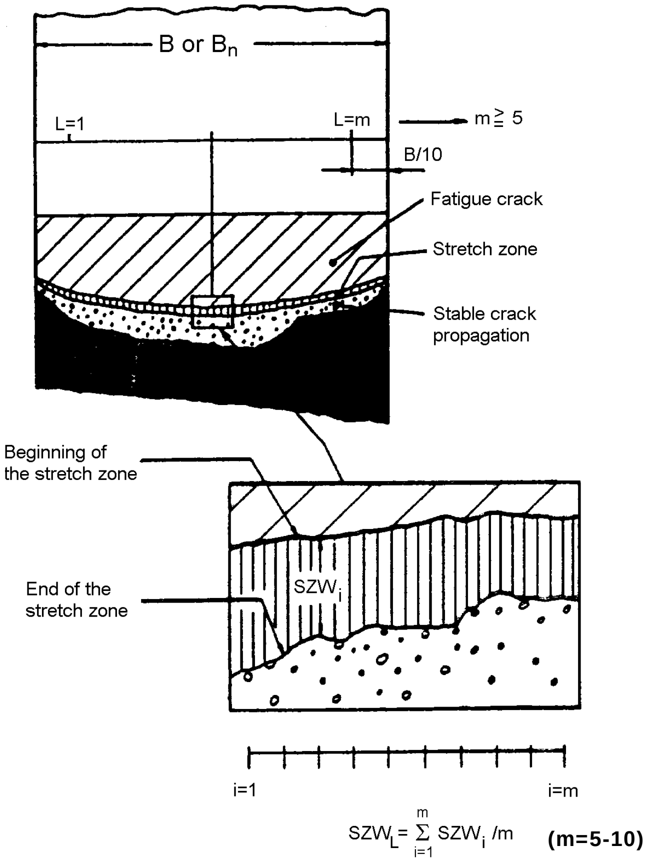

Figure 1. Stretch zone measurement

1. Fatigue crack zone – this zone is present due to specimen preparation: specimens are initially fatigue-loaded in order to extend the machined notch a prescribed amount.
2. Stretch zone – this zone is found to stretch between fatigue crack and stable crack propagation. Size of this zone depends on the toughness of the material around the crack tip and thus is in correlation with K_{IC}.
3. Stable crack propagation – zone of stable crack propagation continues beyond the stretch throughout the whole cross section until the specimen fails.

The best results are obtained if the average value of SZW and the deviation are taken into account. These values can be calculated from values obtained from SEM fracture surface image at several points, usually equally spaced along the specimen width. When SZW is known, the corresponding critical J integral value could be determined, as shown in Fig. 2.

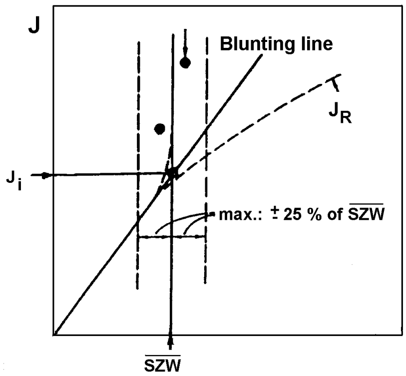

Figure 2. Determination of J_i from stretch zone size.

MATERIALS AND EXPERIMENT

The tested material of interest is MP35N multiphase alloy (35% Co, 35% Ni, 20% Cr and 10% Mo), which exhibits an impressive combination of high strength and toughness after extensive plastic strain (e.g. 53% of cold-working) and subsequent aging at about 600°C for 4 hours. Previous studies of MP35N properties, including fracture toughness testing, have indicated a further possibility for toughness enhancement, which underlines the importance for better understanding fracture behaviour of this material, /5-6/. Therefore, an extensive investigation of elastic-plastic fracture behaviour of commercially cold-drawn MP35N in both unaged and aged conditions has been done.

MP35N fracture behaviour is investigated both under static loading conditions (J-R curve and J_{IC} testing according to ASTM E1737) and under impact loading on Charpy instrumented pendulum. The standard static fracture mechanics testing is performed in order to evaluate the resistance of the aged and unaged MP35N alloy to the stable (e.g. the blunting effect) and unstable crack growth and to investigate the influence of crack orientation.

RESULTS AND DISCUSSION

Fracture surface SEM microphotographs of 3 specimens (3-point bending bars, 10 mm width, as-drawn and unaged state) are obtained. One of the specimens is tested according to standard Charpy tests (without pre-crack), while the other two are tested to static (J_{IC}) and dynamic (J_{Id}) conditions, as shown in /4-6/. For the sample without the pre-crack it was not possible to observe the stretch zone.

Figure 3 shows the fractured surface of specimen 01 exposed to the dynamic loading condition at a relatively small magnification. The change in the fracture surface microstructure from pre-notch toward the zone of stable crack propagation is shown in detailed images.

The microstructure of the stretch zone suggests that mixed loading conditions (elastic-plastic) are predominant around the crack tip at the stage of crack initiation. An inclusion at the beginning of the stretch zone is shown in Fig. 4 (for the same test sample as in Fig. 3).

Results for sample 2 are shown in Fig. 5. One can notice equiaxed dimples in the zone of stable crack propagation (Figure 5B), which is an usual way of microvoid coalescence when uniaxial loading conditions are applied, but not for bending. Elongated dimples can be observed in sample 02 microphotographs. From detail B one can measure 1-1’, 2-2’ … 5-5’ distances and calculate the average SZW_L as:

$$SZW_L = \sum_{i=1}^{m} \frac{SZW_i}{m} \tag{1}$$

Measured values for sample 02 are shown in Table 1. Average SZW is found to be 318 μm. This value could be compared with J_{IC}.

Table 1. SWZ_i values according to Fig. 5B.

Section	1-1’	2-2’	3-3’	4-4’	5-5’	Average
SZW_i (μm)	269	315	331	331	346	318

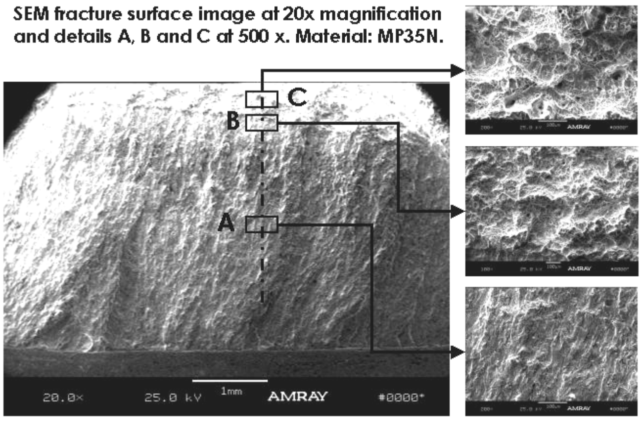

Figure 3. SEM image of fractured surface of 3-point bending bar (MP35N): A – Fatigue crack; B – Stretch zone; and C – Stable crack propagation.

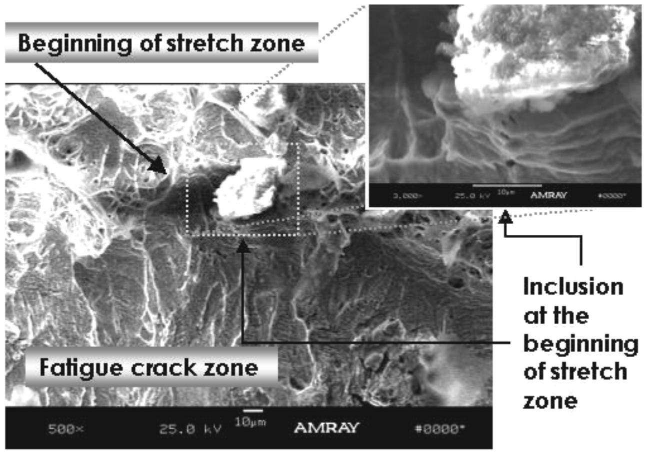

Figure 4. Stretch zone beginning.

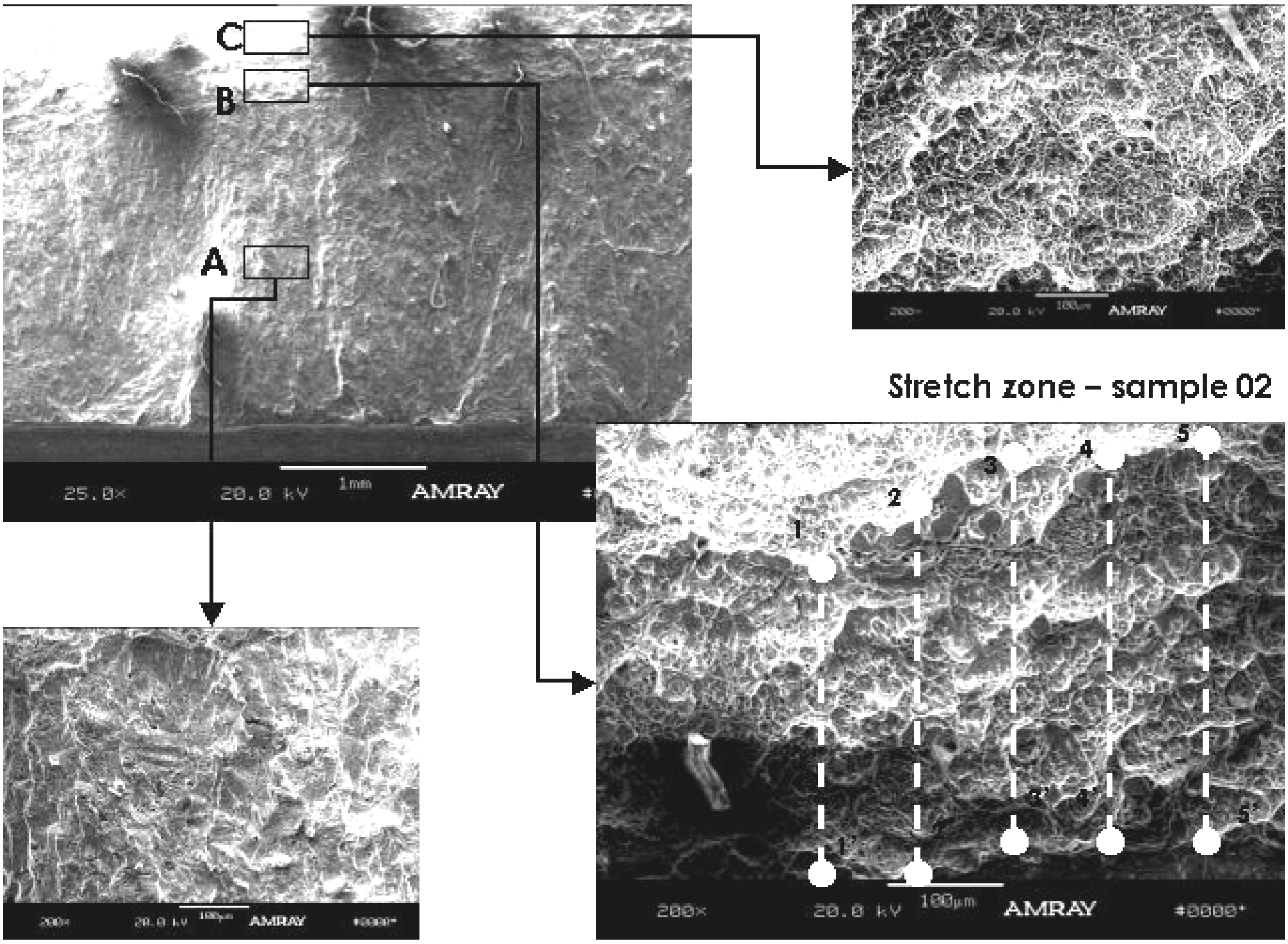

Figure 5. SEM image of fractured surface of 3-point bending bar for MP35N, test sample 02: A – Fatigue crack; B – Stretch zone; and C – Stable crack propagation.

Elastic-plastic fracture mechanics parameters are tested using three point bending specimen, and results are given as J-Δa static curve in graphical form, Fig. 6.

The obtained J_i value is 150 N/mm. The corresponding value for FSW is 220 μm, being cca. 70% of average measured value (318 μm, Table 1). Also, if one uses 318 μm and obtains J_i cca. 200 N/mm from Fig. 6, the difference is still at the same level. Anyhow, having in mind the difference between J_i and J_{IC}, this is an acceptable error in predicting critical elasto-plastic fracture mechanics parameters.

The difference between initial blunting SZ (200 μm) and FSZ (220 μm), is obtained according to the slope of the curve in Fig. 6, in the following way: J_i (150 N/mm) divided by 2 × yield strength (cca. 3000 MPa, /4-6/), equals 20 μm.

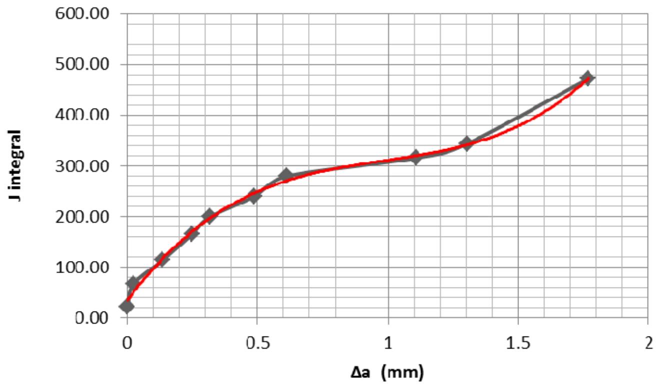

Figure 6. The J-R curve for MP35N multiphase alloy.

CONCLUSION

Fracture surface SEM microphotographs of three specimens are captured, and the microstructure of the stretch zone is analysed. It is shown that at the stage of crack initiation, mixed loading conditions are predominant around the crack tip. One of the main tasks is to determine the final stretch zone width for the MP35N alloy, using the SEM microphotograph of the fractured surface. The results of this study indicate that it is possible to correlate J_{IC} values with obtained average SZW, but only approximately.

ACKNOWLEDGEMENTS

The research work is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, under the number TR 35040. The SEM characterization of the fractured surface is performed at the Materials Engineering Department, Drexel University, PA, USA.

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